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Adaptive Slotted ALOHA based P-Persistent CSMA MAC Protocol for Wireless Sensor Networks

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ABSTRACT
Restricted energy sources for wireless sensor networks have resulted in a number of energy-efficient MAC protocols being proposed and improved. These proposed protocols tried to reduce the energy dissipation and to prolong the network lifetime. An adaptive slotted ALOHA based p-persistent CSMA MAC protocol has been proposed in this paper. The proposed protocol addresses the vulnerabilities of both the slotted ALOHA and the p-persistent CSMA protocols, such as the high possibility of collision, force the stations to transmit at the start of the slot, fixed slot length, and continuous sensing in the P-persistent CSMA MAC protocol. The proposed protocol aims to reduce collision potential, reduce sensing, minimize energy expenditure, and maximize network lifetime. MATLAB simulation has been used for the evaluation of the protocol's performance and effectiveness. The simulation results displayed that the improvement rate for the proposed adaptive slotted ALOHA based p-persistent CSMA MAC protocol was 95%, 95%, 96.88%, 99.82%, and 99.77% compared to pure ALOHA, slotted ALOHA, p-persistent CSMA, S-MAC, and T-MAC protocols respectively in terms of number of alive nodes and energy consumption. As a result, the proposed protocol has dramatically enhanced the network of wireless sensors in terms of minimizing energy consumption and extending the life of the network.

Keywords-- Adaptive Slotted-ALOHA, energy-efficient MAC protocols, p-persistent CSMA, slotted-ALOHA, wireless sensor networks (WSNs)

INTRODUCTION

Wireless Sensor Networks (WSNs) have been considered to be one of the modern techniques that play an important role in our lives. WSNs have been used in a lot of applications such as environmental monitoring, entertainment, military, retail industrial control, security, emergency, medical, and health [1]. In general, many sensor nodes are connected to each other, creating WSN. The sensor nodes are characterized by their small size and operate on the battery. The main components of the sensor node are the sensing unit used for sensing events such as temperature sensors, humidity sensors, pressure sensors, etc. analog to digital converter (ADC) for converting analog sensing signals to digital signals, the transceiver used for transmitting and receiving processes, and the power supply to power the sensor node. Fig. 1 shows the architecture of the node of the sensor [2].

The challenge of replacing the battery sensor due to the huge number of distributed sensor nodes and the difficulty of reaching it in remote areas has led to the proposed energy-efficient MAC protocols. MAC protocols play a crucial role in ensuring that WSN networks operate efficiently. MAC protocols usually consist of two simple groups: asynchronous and synchronous MAC protocols. In asynchronous MAC protocol, nodes compete with each other to reserve a channel. In synchronous MAC protocol, each node reserves the channel for a specific time based on a schedule [3].

As a large proportion of energy is wasted in the transceiver unit, the processes of sensing the channel, collisions, idle-listening, over-hearing that spent extra energy must be reduced. In this paper, an adaptive ALOHA-based p-persistent CSMA MAC protocol was proposed to reduce the probability of collisions; idle-listening, continuous channel sensing.

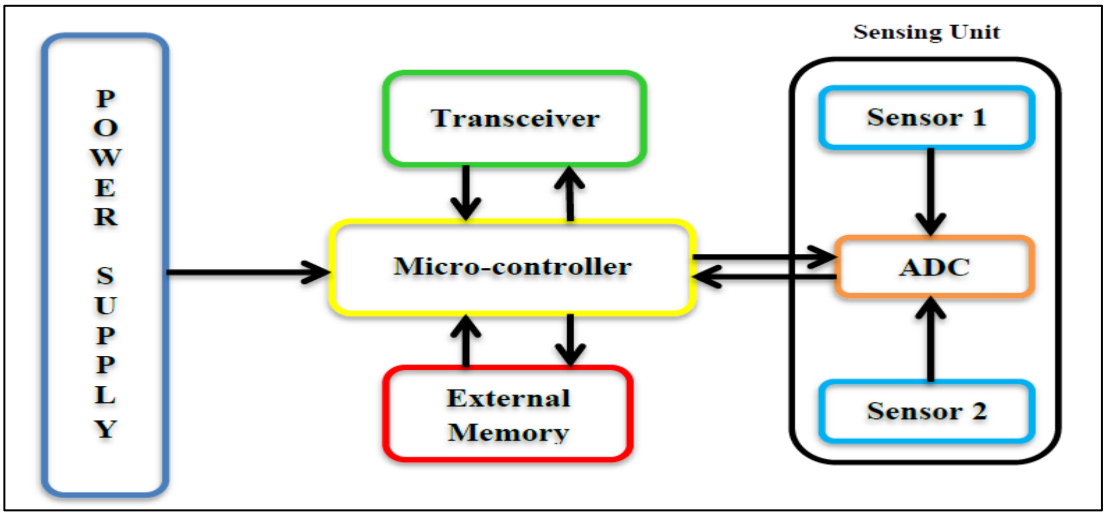

Figure 1: *The architecture of the sensor node.*

RELATED WORK

Researchers have developed and suggested a wide range of energy-efficient MAC protocols due to the critical role of MAC protocols in the conservation of energy and the expansion of network lifetime. Beakcheol Jang and et al. introduce an energy-efficient MAC protocol for wireless sensor networks which avoids over-hearing, decreases delay, and decreases contention by scheduling the time to wake up neighboring nodes asynchronously [4].

Lulu Liang and et al. proposed a low latency MAC protocol by modifying the Sleep Window (SW-MAC) [5]. Sleep window is modified by the process of additive increase/multiplication decrease for high variance flow. A scout-based scheduling mechanism was then designed to reduce delivery latency.

Guijuan Wanga and et al. propose demand sleep MAC (DS-MAC) that enables nodes to adapt their sleep time according to the number of data packets received in order to provide effective communication in dynamic traffic loads [6]. To wake up the recipient, The DS-MAC protocol is trying to send a number of short token packets to avoid overhearing problems. In DS-MAC, the prediction field is inserted into ACK packets, thus, reducing the delay time of the source node.

Younas Khan and et al. suggested Extended Traffic-Aware Energy-Efficient MAC (TEEM) protocol to diminish the idle listening time and reduce overhead through change node state into sleep mode when there is no data ready for sending [7].

The authors proposed an energy-efficient Fast Traffic Adaptive MAC (FTA-MAC) protocol for WSNs [8]. In the case of FTA-MAC, the receiving nodes initiate communication by transmitting a wake-up beacon, depending on the traffic rate, to decrease idle listening periods, thereby decreasing energy consumption.

Ananda Kumar Subramanian and Ilango Paramasivam have introduced the Priority in Node (PRIN) MAC protocol, which reduces the amount of energy consumed and extends the life of the network by assigning different priorities to incoming packets based on the arrival priority queue [9].

An Improved Sensor MAC (IS-MAC) protocol has been presented to prevent data collisions in wireless passive sensor networks (WPSNs) [10]. The IS-MAC protocol selects the appropriate contention window based on the current load of the network to conserve energy.

ENERGY MODELS

The amount of energy needed to transmit/receive data by the sensor node is given in Equations (1) and (2). The energy model can be found in Fig. 2 [11].

$$E_{TX}(k,d) = \begin{cases} E_{elec} \times k + \varepsilon_{fs} \times k \times d^2 & , d < d_0 \\ E_{elec} \times k + \varepsilon_{amp} \times k \times d^4 & , d \geq d_0 \end{cases} \quad (1)$$

$$E_{RX}(k,d) = \mathrm{E_{elec}} \times \mathrm{k} \quad (2)$$

Where:

E_{TX}/E_{RX}: is the energy dissipated to transmit/receive k bits of data.

E_{elec}: is the energy dissipated in the modulation.

ε_{fs}, ε_{amp}: is the energy dissipated in the amplification.

k: number of bits.

d: is the distance between source and destination.

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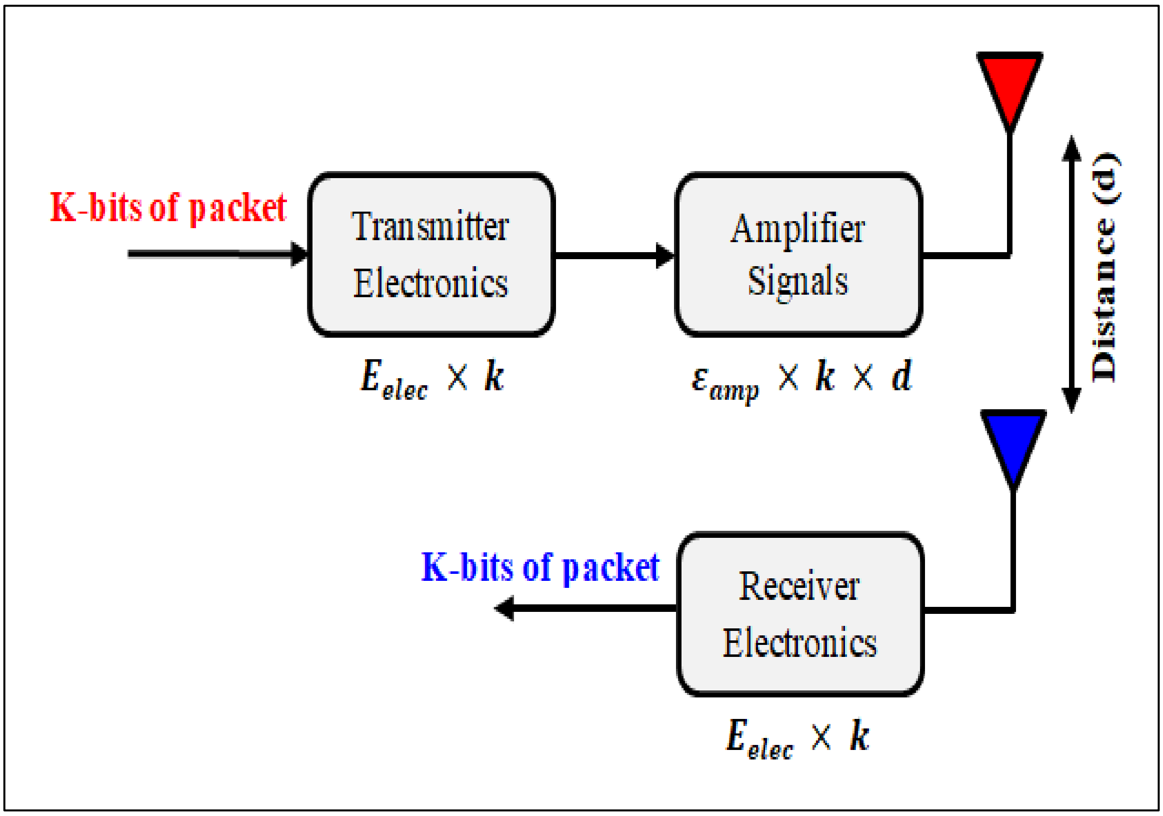

Figure 2: *Energy model of WSNs.*

PROPOSED MAC PROTOCOL

An adaptive slotted ALOHA based on p-persistent CSMA MAC protocol has been proposed to minimize the energy consumption of both slotted ALOHA and p-persistent CSMA resulting from the collision and continuous channel sensing. In the suggested protocol, the channel is divided into slots as it is in the slotted ALOHA. These time slots are characterized by their different length based on the size of the data. Each station (node) has a random number (*r*) between (0) and (1) as per the p-persistent CSMA protocol. The random number for each node is given using the rand function in MATLAB (The rand function generates a n×n matrix with pseudorandom values between 0 and 1). If a station has a frame ready for transmitting, it is first checked that the channel is idle or occupied. If a channel is discovered free, the station compares its *r* value to the predefined threshold in Equation (3) [12]. The station would be able to transmit only if the station's r value is less than the threshold value and the channel is idle. Fig. 3 provides an example of sending frames using the proposed protocol.

$$P - threshold = \left(1 - \frac{1}{N}\right)^{N-1} \qquad (3)$$

Where:

N: represents the number of nodes.

There are four stations competing with each other to reach the shared channel. When a station has a frame to send, it senses the channel for idle first. At slot 1, station 1 and station 2 have a frame to send, so they check the channel and find it busy. So, they are going to wait for the next slot plus back-off time (T_B) to check the channel again. At slot 2, both station 1 and station 2 re-check the channel, since station 2 had a lower T_B than station 1 it would check the channel faster than station 1 and reserve it for transmission after comparing its *r* value to *P-threshold* and finding it less than *P-threshold*. As a result, when station 1 checks the channel at the end of its T_B, it finds the channel busy with station 2 and waits for the next slot that starts after 500 bytes of station 2 have been sent. At slot 3, besides station 1, station 3 has a frame ready to be transmitted before the end of station 1 T_B. Station 3 senses the channel and finds it idle so that it reserves the channel and sends its frame. At slot 4, station 4 finds the channel free but its *r* value is greater than the value of the *P-threshold* value and does not have permission to transmit in this slot and hangs its frame to the next slot, while station 3 transmits its frame after finding the channel free. Finally, station 4 sends its frame at slot 5.

As seen in Fig. 3, the chance of collision is significantly reduced compared to the slotted ALOHA protocol and, at the same time, the periodic sensing is reduced compared to the p-persistent CSMA protocol. As a result, a large amount of energy will be conserved and the lifetime of the network will be extended.

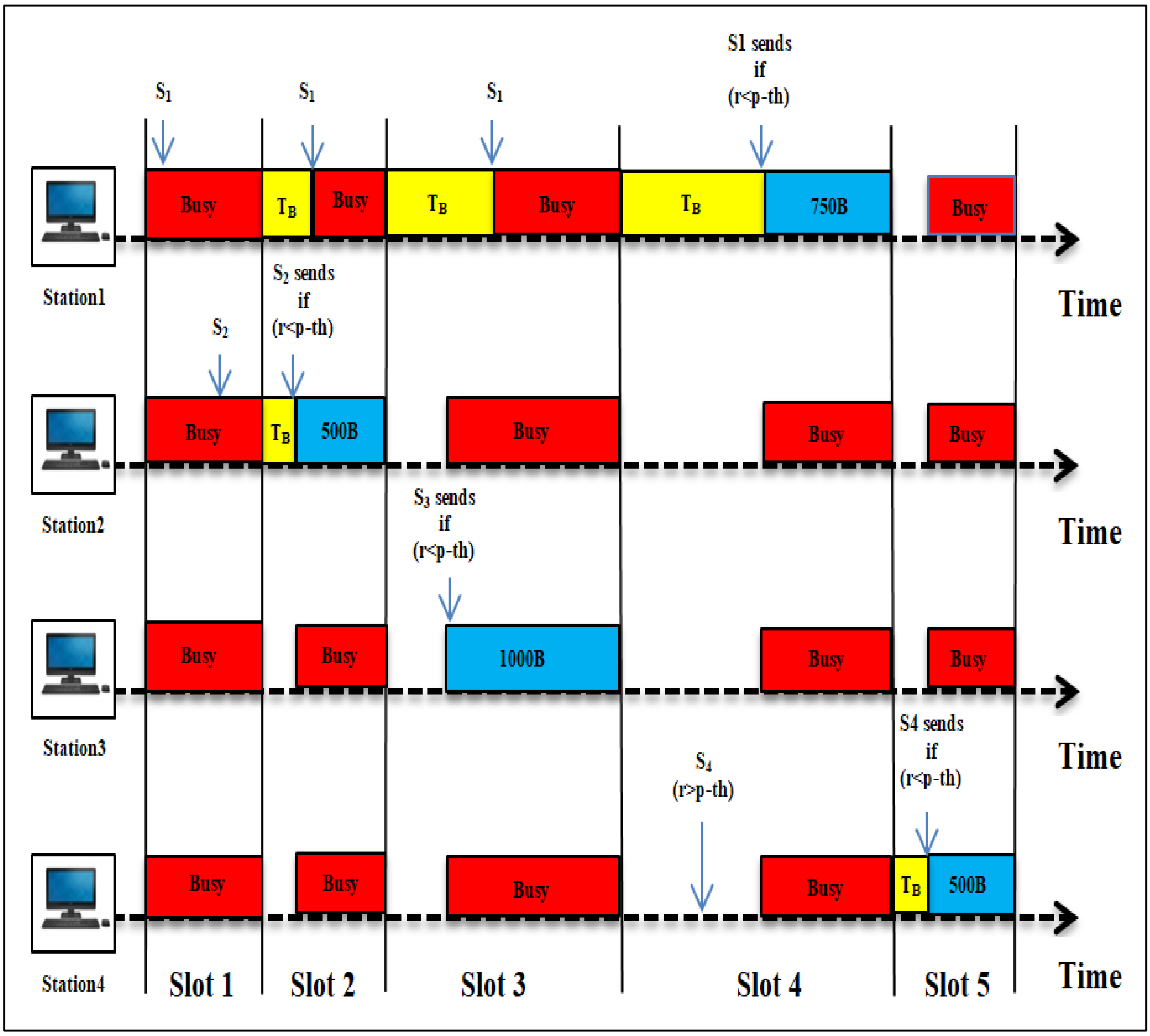

Figure 3: *Sending frames using the proposed adaptive slotted ALOHA based p-persistent CSMA MAC protocol.*

SIMULATION RESULTS

The proposed protocol is used in the monitoring field with an area 100 × 100 m^2. The area of monitoring is divided into clusters in the form of triangles. Every cluster consists of 10 sensor nodes as shown in Fig. 4. There are two types of manually distributed sensor nodes that are Cluster Member (CM) and Cluster Head (CH). The primary task of CHs is to collect data from CMs in the same cluster and to relay the data collected to the base station located at the center of the monitoring area. Alive nodes, energy consumption, residual energy, network stability, and network lifetime metrics are used to estimate the performance of the network.

A comparison is made with pure ALOHA, slotted ALOHA, p-persistent CSMA, S-MAC, and T-MAC protocols using MATLAB simulation program in order to evaluate the performance of the proposed protocol [13]. In order to validate the performance of the proposed MAC protocol, the proposed protocol was evaluated in four different scenarios and the results were compared with other MAC protocols to demonstrate its efficiency. Simulation parameters are shown in Table 1.

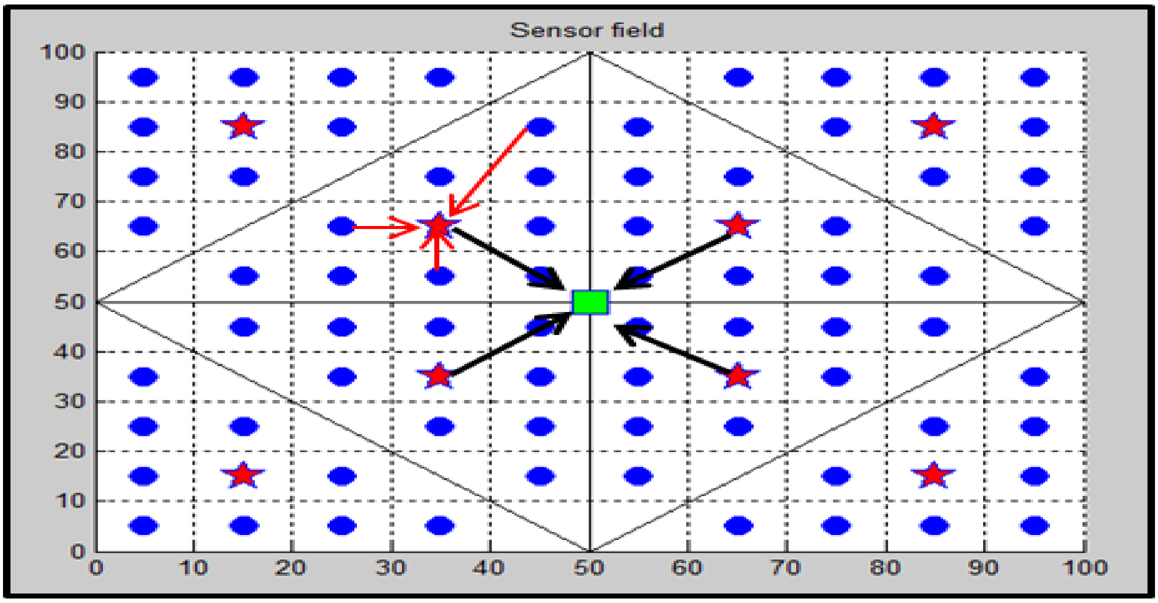

Figure 4: *The network model for the proposed MAC protocol.*

NN CH BS

Table 1: *Simulation parameters.*

Parameter	1st Scenario	2nd Scenario	3rd Scenario [13]
Area of Sensor Field	100 × 100 m^2	100 × 100 m^2	100 × 100 m^2
Base Station Position	(50,50)	(50,50)	(50,50)
Number of Nodes	80	80	10
Number of CH	8	8	-
Number of NN	72	72	10
Initial Energy	NN = 0.1J CH = 2J	NN = 0.1J CH = 2J	100J
ε_{amp}	100pJ/bit/m^2	100pJ/bit/m^2	100pJ/bit/m^2
E_{elec}	50nJ/bit	50nJ/bit	50nJ/bit
Packet Size	250bytes	500bytes	512bytes

FIRST SCENARIO

In this scenario, the performance of the proposed MAC protocol is estimated compared to pure ALOHA, slotted ALOHA, and p-persistent CSMA protocols. As explained in Fig. 5, the proposed MAC protocol achieves significant improvements compared with other protocols. The possibility of collision in a particular cluster is significantly reduced in the proposed protocol comparable to the slotted ALOHA protocol and, at the same time, the cyclic sensing is reduced compared to the p-persistent CSMA protocol by obliging the node to check the channel for idly at each slot prior to transmission and allowing it to transmit only if the *r* value is less than the *P-threshold* value. As a result, a large amount of energy will be conserved and nodes will remain alive longer than other protocols.

As can be seen in Fig. 5, the proposed MAC protocol gives better performance compared to other protocols in terms of alive nodes. At round 1000, the number of alive nodes is 80 for the proposed protocol, while 4 nodes remain alive in pure ALOHA, which shows that the proposed protocol improved pure ALOHA by 95% in terms of the number of alive nodes. At round 2000, the number of alive nodes is remains 80 for the proposed protocol, while 4 nodes remain alive in slotted ALOHA, which shows that the proposed protocol improved slotted ALOHA by 95% in terms of the number of alive nodes. At round 3000, the number of alive nodes is 64 for the proposed protocol, while 2 nodes remain alive in p-persistent CSMA protocol, which shows that the proposed protocol improved p-persistent CSMA by 96.875% in terms of the number of alive nodes. These significant improvement rates return to the use of adaptive slotted ALOHA and sense the channel at each slot before transmission, which reduces collisions, reduces energy consumption, and, thus, increases the lifetime of the network.

As displayed in Fig. 6, the proposed protocol has more energy-efficient than other protocols. The reduction in the amount of residual energy for other protocols is higher than the reduction in the proposed protocol.

As presented in Fig. 7, the network remained stable until round 494, 989, 1353, and 2560 in pure ALOHA, slotted ALOHA, p-persistent CSMA, and proposed protocol, respectively. Where the results have shown that the proposed protocol is more stable than other protocols.

Fig. 8 demonstrates the death of the last nodes in each protocol. The last node died in pure ALOHA in round 1250. The last node died in slotted ALOHA in rounds 2500. In the p-persistent CSMA, the last node died in round 3250. In the case of the proposed protocol, the death of the last node was not determined because of the increasing difficulty of executing the code for a long time. As noticed in Fig. 8, the proposed protocol greatly expands the network lifetime compared to other protocols.

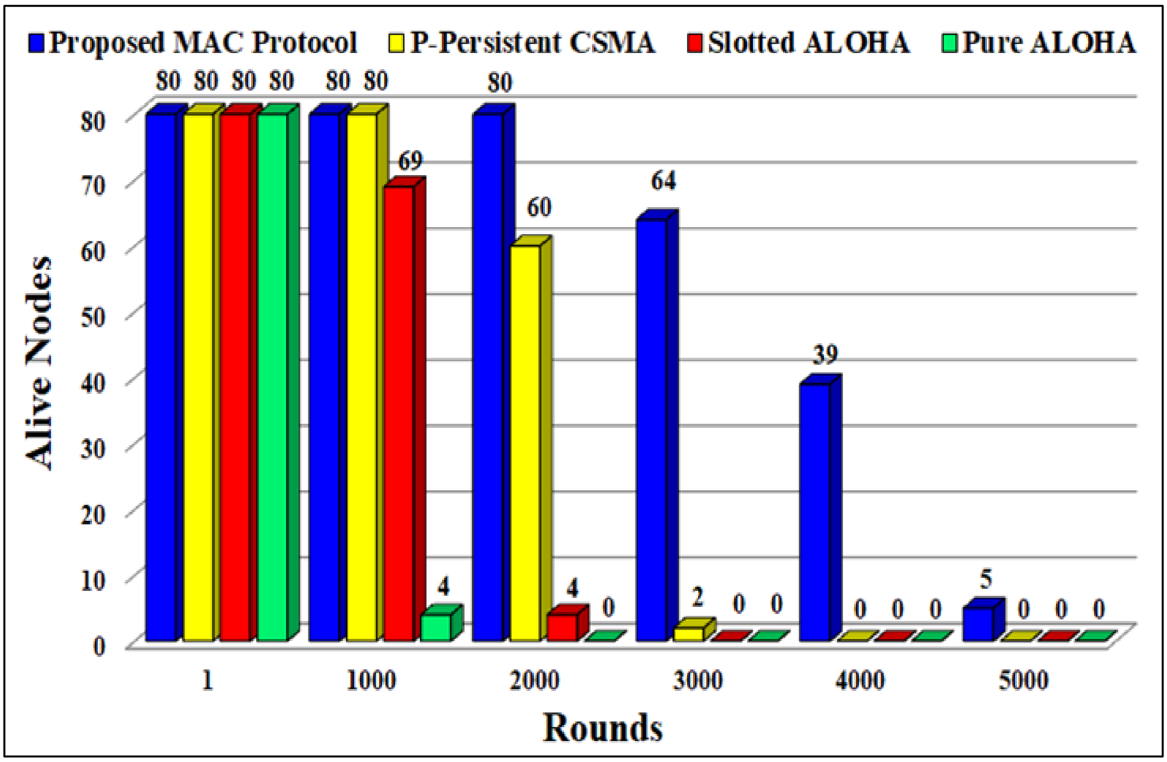

Figure 5: *Number of alive nodes over time in pure ALOHA, slotted ALOHA, p-persistent CSMA, and the proposed MAC protocols.*

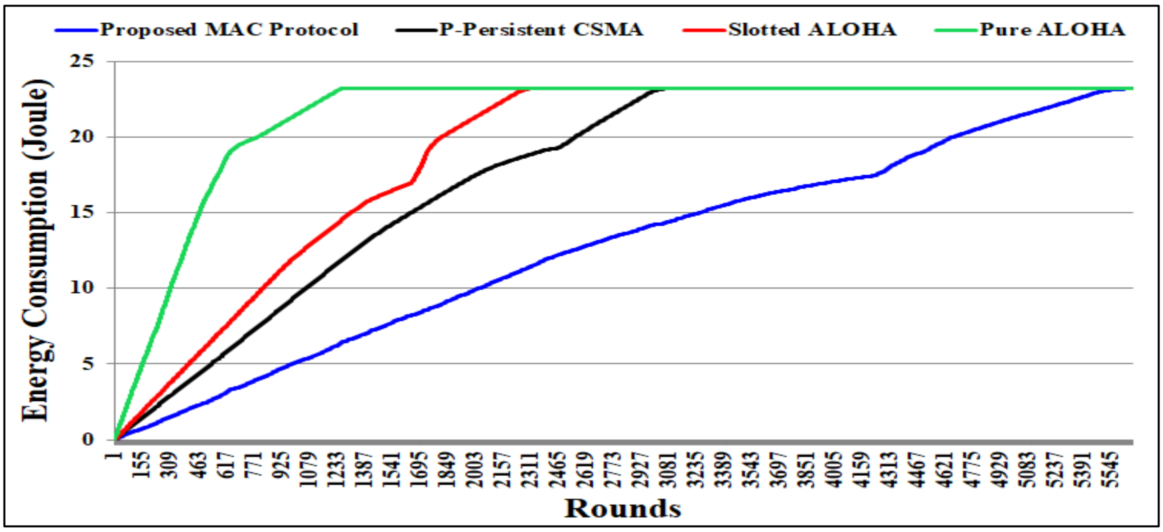

Figure 6: *Energy consumption over time in pure ALOHA, slotted ALOHA, p-persistent CSMA and the proposed MAC protocols.*

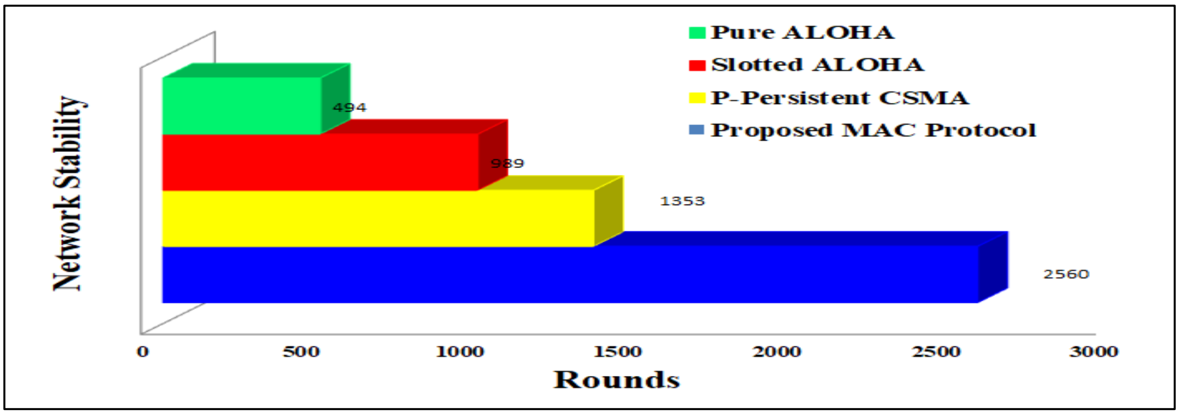

Figure 7: *Network stability over time in pure ALOHA, slotted ALOHA, p-persistent CSMA and the proposed MAC protocols.*

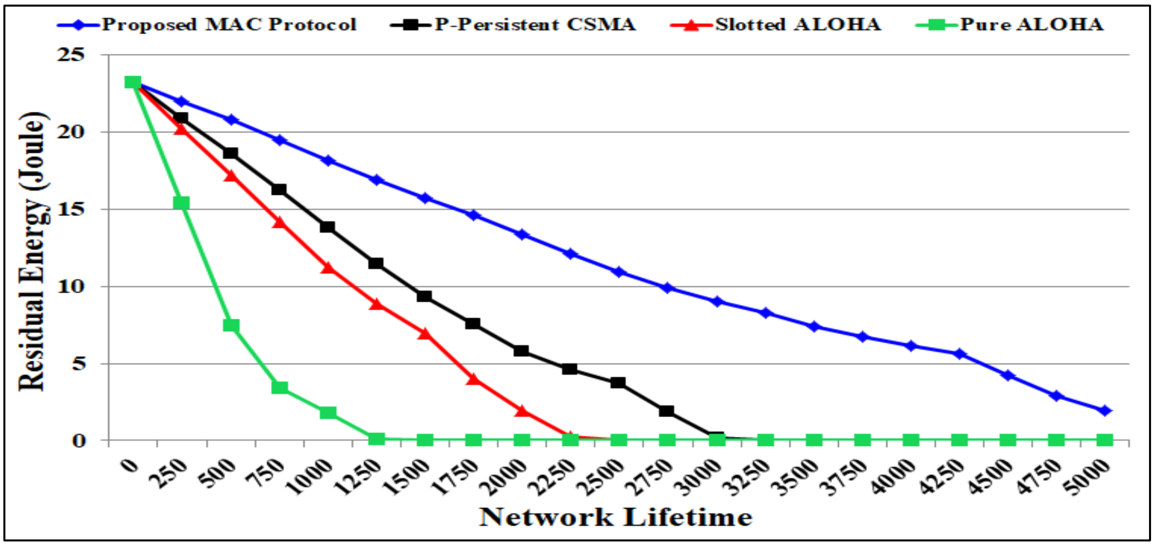

Figure 8: *Network lifetime over time in pure ALOHA, slotted ALOHA, p-persistent CSMA and the proposed MAC protocols.*

SECOND SCENARIO

In this scenario, the effect of packet size on the proposed protocol is being analyzed. As can be seen in Fig. 9, the increase in the size of the packet has resulted in an increase in the dissipation of energy, thereby speeding up the death of the nodes.

Fig. 10 illustrates how the change in the size of the packet contributes to a rise in energy consumption over time.

Fig. 11 demonstrates the effect of adjusting the size of the packet on the death of the first node. The death of the first node delays when using a small packet size. As a consequence, network stability improves as the packet size is minimized.

Packet size plays an important role in increasing or reducing the lifetime of the network. As can be seen in Fig. 12, the reduction in packet size resulted in an expansion of the network lifetime and vice versa.

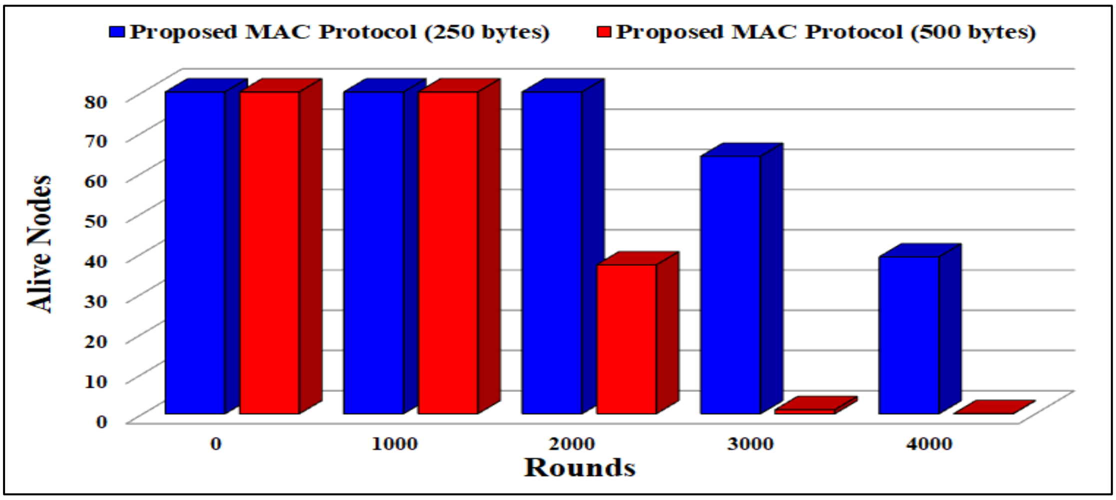

Figure 9: *Number of alive nodes over time in the proposed protocol using a different packet size.*

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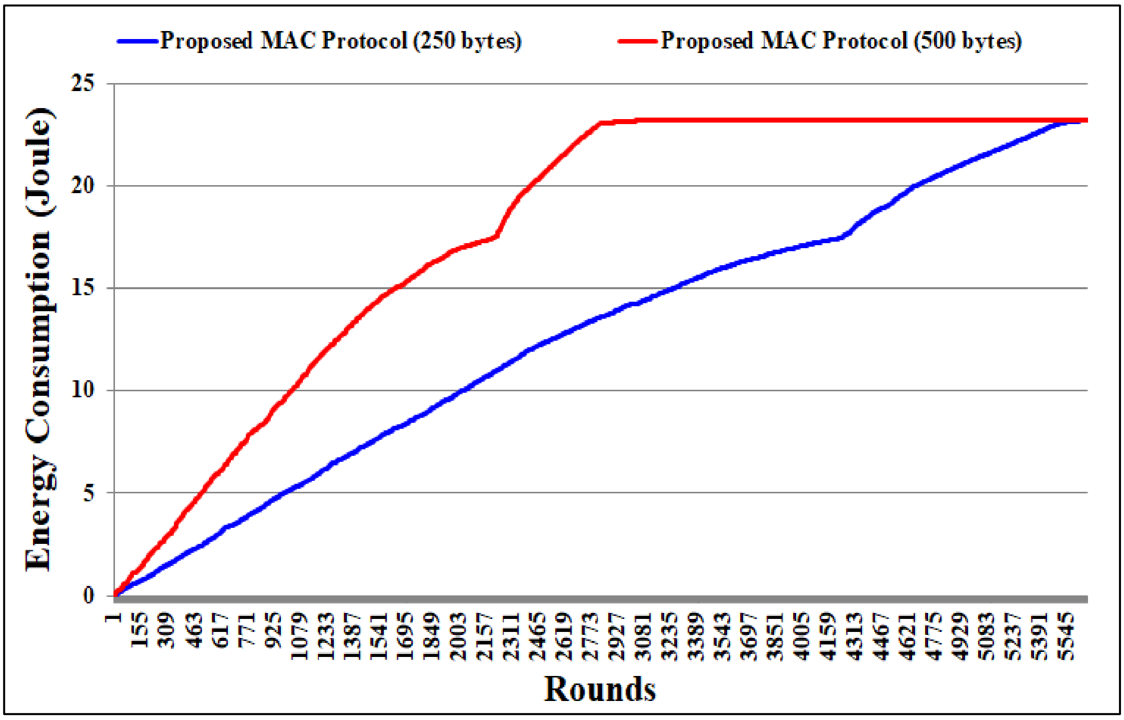

Figure 10: Energy consumption in the proposed protocol using a different packet size

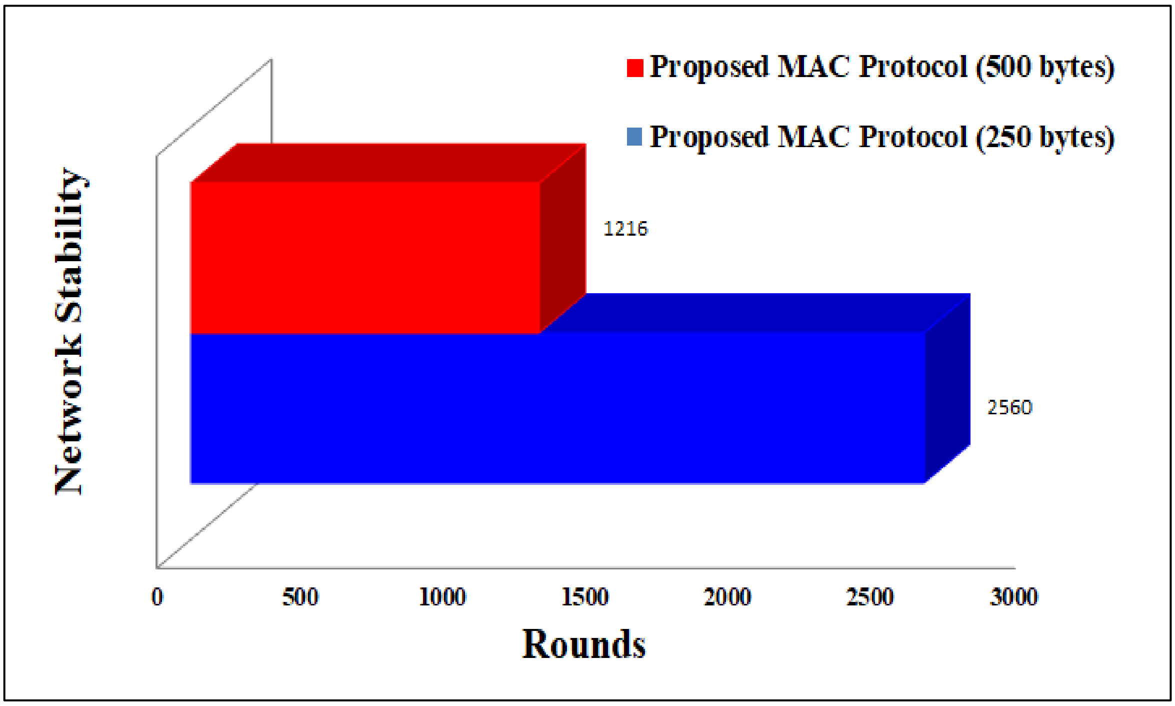

Figure 11: *Network stability in the proposed protocol using a different packet size*.

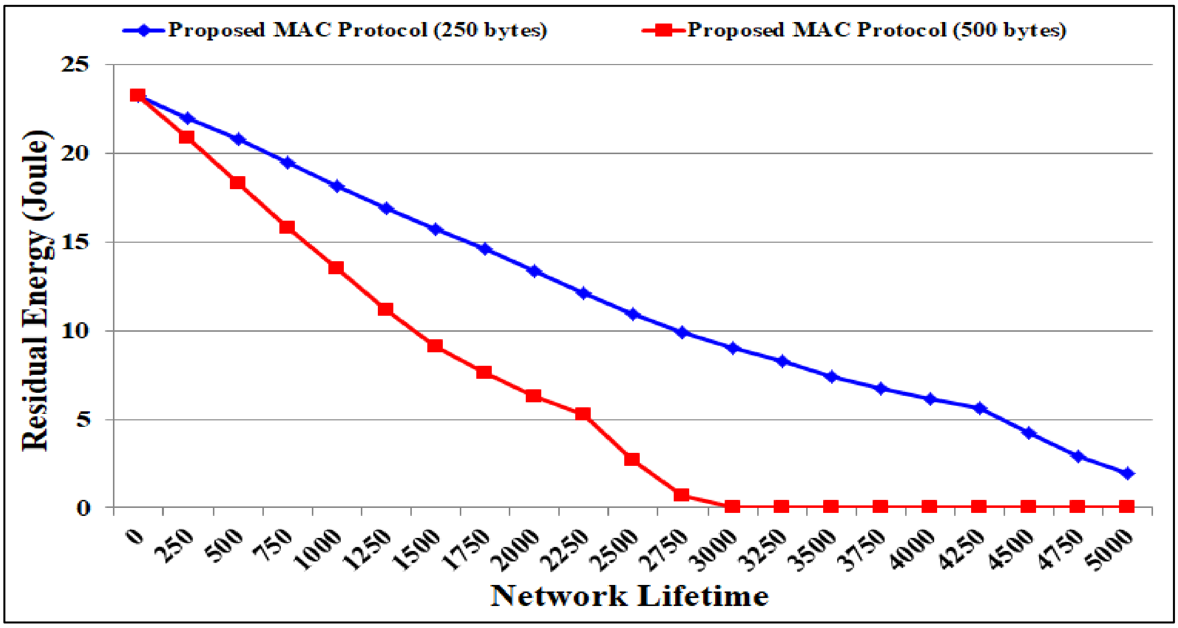

Figure 12: *Network lifetime in the proposed protocol using a different packet size.*

THIRD SCENARIO

In this scenario, the proposed protocol was operated under conditions similar to the network conditions used in order to provide a fair comparison between the proposed MAC protocol and the protocols referred [13]. The proposed protocol is applied to 10 sensor nodes scattered in the 100 × 100 m^2 area sensor field. When an event occurs, the sensor node detects the event and transmits it directly to the BS located at the center of the sensor scope as shown in Fig. 13.

Fig. 14 indicates the effects of the comparison of the S-MAC and T-MAC protocols relative to the efficiency of the proposed MAC protocol in terms of energy consumption [13]. Due to the reduction of the exchange of ACK and RTS/CTS synchronous packets, reducing idle-listening that S-MAC and T-

MAC suffer, and reducing collisions before transmitting by the sense of the channel, the proposed MAC protocol outperforms the S-MAC and T-MAC protocols, thereby reducing energy dissipation and increasing network lifetime.

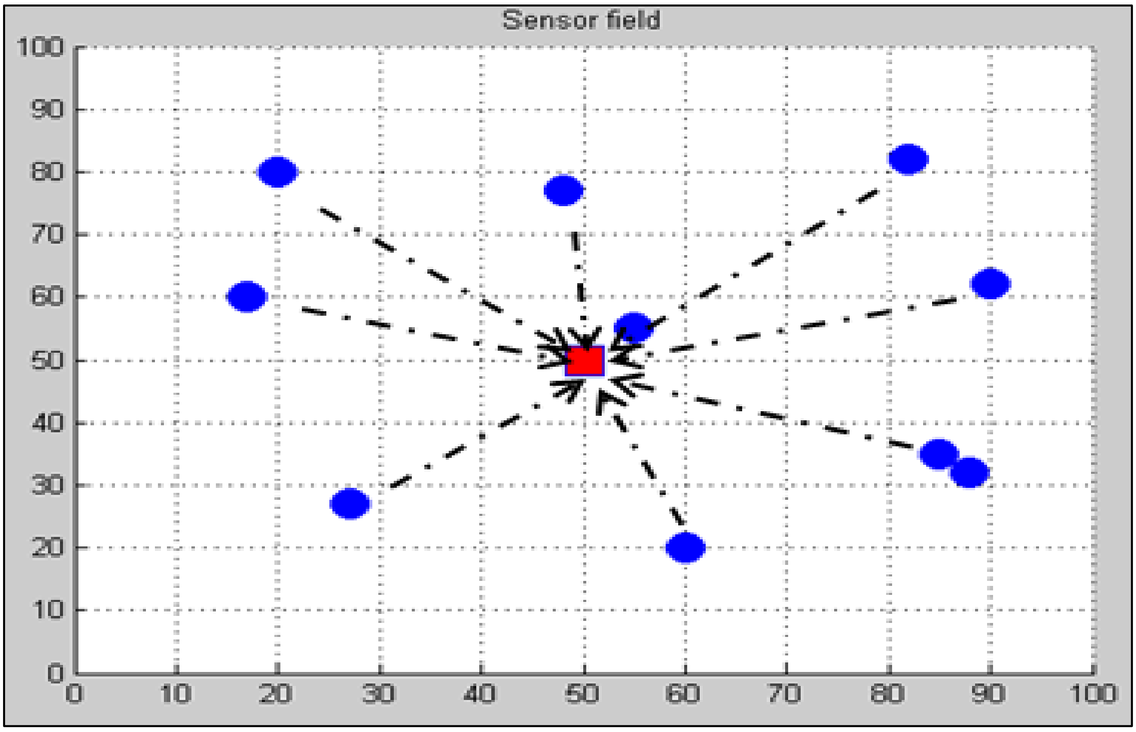

Figure 13: *Sensor scope of the third scenario.*

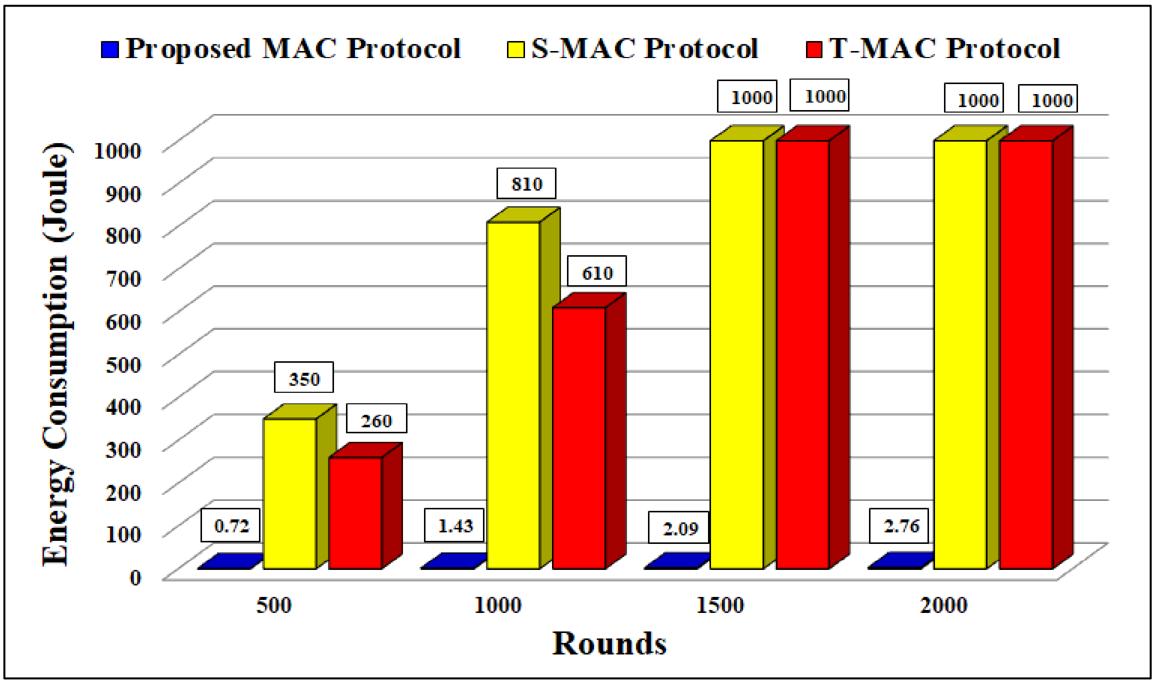

Figure 14*: Energy consumption comparison of S-MAC, T-MAC and proposed protocol.*

Table 2 summarizes the results obtained in terms of the number of alive nodes, the amount of energy consumed, and the rate of improvement.

Table 2: *Summary of the results achieved.*

Scenarios	**Initial Energy of NN**	**Initial Energy of CH**	**Protocols**	**Rounds**	**Alive Nodes/ Energy Consumption**	**Improvement Rate**	
First	0.1J	2J	Proposed MAC Protocol	1000	80	-	
				2000	80		
				3000	64		
				4000	39		
			P-persistent CSMA	1000	80	At round 3000	96.875%
				2000	60		
				3000	2		
				4000	0		
			Slotted ALOHA	1000	69	At round 2000	95%
				2000	4		
				3000	0		
				4000	0		
			Pure ALOHA	1000	4	At round 1000	95%
				2000	0		
				3000	0		
				4000	0		
Second	0.1J	2J	Proposed MAC Protocol (250 bytes)	2000	80	At round 3000	98.438%
				3000	64		
				4000	39		
			Proposed MAC Protocol (500 bytes)	2000	37		
				3000	1		
				4000	0		
Third [13]	100J	100J	Proposed MAC Protocol	500	0.72J	-	
				1000	1.43J		
				1500	2,09J		
			S-MAC	500	350J	At round 1000	99.82%
				1000	810J		
				1500	1000J		
			T-MAC	500	260J	At round 1000	99.77%
				1000	610J		
				1500	1000J		

CONCLUSION

The constrained energy that the wireless sensor networks are suffering has led to the suggestion of several MAC protocols to extend the life of the network. The adaptive slotted ALOHA based p-persistent CSMA MAC protocol is presented in this paper to minimize energy dissipation, and maximize the network lifetime. The results indicate that the improvement rate for the proposed adaptive slotted ALOHA based p-persistent CSMA MAC protocol was 95%, 95%, 96.88%, compared to pure ALOHA, slotted ALOHA, p-persistent CSMA, in terms of the number of alive nodes and 99.82%, 99.77% compared to S-MAC, and T-MAC protocols respectively in terms of energy consumption due to the high possibility of collisions, idle-listening, continuous sensing problems that consume extra energy in other protocols.

REFERENCES

1. H. Yetgin, K. T. K. Cheung, M. El-Hajjar, L. Hanzo (2017), "A survey of network lifetime maximization techniques in wireless sensor networks", *IEEE Commun. Sur. & Tutor.*, Volume 19, Issue 2, pp. 828-854.
2. N. R. Patel, S. Kumar (2018), "Wireless sensor networks challenges and future prospects", *International Conference on System Modeling & Advancement in Research Trends (SMART)*.
3. M. N. Riaz, M. N. Qureshi, A. Mahboob, "Energy efficient MAC protocols for wireless sensor networks: A survey", *Internat. J. of Scient. & Eng. Res.*, Volume 4, Issue 5, pp. 1859-1879.
4. B. Jang, J. B. Lim, M. L. Sichitiu (2013), "An asynchronous scheduled MAC protocol for wireless sensor networks", *Comp. Net.* Volume 57, pp. 85-98.
5. L. Liang, X. Liu, Y. Wang, W. Feng, G. Yang (2014), "SW-MAC: A low-latency MAC protocol with adaptive sleeping for wireless sensor networks", *Wire. Per. Commun.*, Volume 77, Issue 2, pp. 1191-1211.
6. G. Wanga, J. Yua, D. Yub, H. Yuc, L. Fengd, P. Liua (2015), "DS-MAC: An energy efficient demand sleep MAC protocol with low latency for wireless sensor networks", *J. of Net. and Comp. App.*, Volume 58, pp. 155-164.
7. Y. Khan, F. A. Khan, S. Ahmed, I. Ahma, S. S. Rahim, M. I. Khattak (2016), "ETEEM- extended traffic aware energy efficient MAC scheme for WSNs", *Internat. J. of Adv. Comp. Sci. and App.*, Volume 7, Issue 11, pp. 272-277, DOI: 10.14569/IJACSA.2016.071134.
8. V. T. Nguyen, M. Gautier, O. Berder (2016), "FTA-MAC: Fast traffic adaptive energy efficient mac protocol for wireless sensor networks", *International Conference on Cognitive Radio Oriented Wireless Networks*.
9. A. K. Subramanian, I. Paramasivam (2017), "PRIN: A priority-based energy efficient MAC protocol for wireless sensor networks varying the sample inter-arrival time", *Wire. Pers. Commun.*, Volume 92, Issue 3, pp. 863-881.
10. Q. Yu, G. Li, X. Hang, K. Fu, T. Li (2017), "An energy efficient MAC protocol for wireless passive sensor networks", *Fut. Inter.*, Volume 9, Issue 2, pp. 14.
11. F. Khanouche, L. Maouche, F. Mir, M. E. Khanouche (2019), "Energy-efficient multi-hops routing protocol based on clusters reorganization for wireless sensor networks", *Proceedings of the 3rd International Conference on Future Networks and Distributed Systems*.
12. "Networking-What is P in P-Persistent CSMA?" Stack Overflow, [Online] Available from: https://stackoverflow.com/questions/39717769/what-is-p-in-p-persistent-csma.
13. R. Munadi, A. Sulistyorini, F. U. Fauzi, T. Adiprabowo (2015), "Simulation and analysis of energy consumption for S-MAC and T-MAC protocols on wireless sensor network", *IEEE Asia Pacific Conference on Wireless and Mobile (APWiMob)*.